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ScienceDirect
Energy Procedia 88 (2016) 394 – 400
Energy Procedia

CUE2015-Applied Energy Symposium and Summit 2015: Low carbon cities and urban energy systems

Match performance analysis for a solar-driven energy system in net zero energy building

Huanhuan Feng[a], Xue Tian[a,b], Sunliang Cao[c], Jun Zhao[a], Shuai Deng[a],*

[a]*Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, MOE, School of Mechanical Engineering, Tianjin University, Tianjin 300072, China*
[b]*Tianjin Eco-city Energy Investment Construction Ltd.CO, Tianjin, 300467, China*
[c]*HVAC Technology, Departmnet of Energy Technology, School of Engineering, Aalto University, FI-00076 Aalto, Finland*

Abstract

Match performance is a critical consideration on the design of energy system for zero energy building/community. A case study regarding an residential building of net zero energy (NZEB) is presented in this article. In addition to the passive design of energy efficient, indoor terminal units and renewable energy power system, an emphasis is placed on solar-driven energy system which employed LiBr and CO_2 as working fluids for a hybrid cycle of vapor compression and absorption. The performance of NZEB was evaluated in terms of the indoor comfort, energy balance and match.

Peer-review under responsibility of the organizing committee of CUE 2015

Keywords: Net zero energy, Energy system, Renewable energy, Solar energy

1. Introduction

Using net zero energy building (NZEB) as an approaching goal of building development, problems on energy and environment can be addressed in an aggressive and integration way. Regarding the NZEB cases, a literature search suggests that most of projects summarized in the introduction section of former publication are focused on a balance research. The case which covers the integration design, the real operation and the match performance analysis of NZEB are both rare. In this article, a case study about a net zero energy building is present. The simulation is conducted for two typical weather conditions in

* Corresponding author. Tel.: 18649119735; fax: +86 22 27404188.
E-mail address: SDeng@tju.edu.cn.

Peer-review under responsibility of the organizing committee of CUE 2015
doi:10.1016/j.egypro.2016.06.010

China based on the existing test. The performance results of NZEB are evaluated in terms of indoor comfort, energy match performance [1], etc.

2. NZEB Description

2.1. Passive Design

The research object is a 90 m^2 house which is a typical architecture design in China for a residential living of 2 adults and 1 kid (fig.1). The real test space with the high performance envelopment is used as a test and demonstration platform for building energy efficiency technologies. The passive design parameters are shown in Table.1.

Table 1. Passive Design Parameters

Component	Surface [m²]	Column A (*t*)	Column B (*T*)
Floor	93	0.30	-
Facade. S	45.9	0.31	-
Facade. N	45.9	0.31	-
Facade. E	32.6	0.31	-
Facade. W	32.6	0.31	-
Roof	93	0.21	-
Window. S	7.92	2.5	0.62
Window. N	10.32	2.5	0.62
Window. E	6.96	2.5	0.62
Window. W	0	-	-
Other features		Two skins facade	

2.2 Energy System

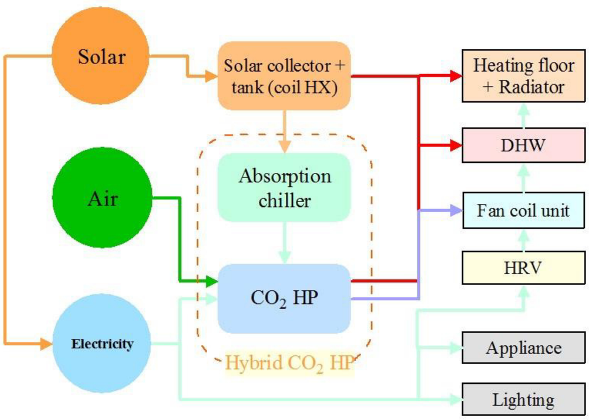


Fig. 1. System configuration(source, supply, demand sides)

The energy system here means the entire service system which meets the main demands of house. It includes solar collector system, HVAC&DHW system, indoor terminal units and renewable energy power system. Figure 1 illustrates the configuration of energy system, concerning the energy flows among sides of source, supply (conversion) and demand. The solar energy is a core source to drive energy system for a multi-generation. The key unit in the system contains a solar collector system and a hybrid CO_2 heat pump. The demands for end user are cooling, heating, DHW, appliance and lighting. A home energy management system (HEMS) will be employed for the entire system.

The solar collector (SC) array is installed on the slope steel frame above the roof of test space as shown in Figure 2. The applied SC is a type of evacuated glass tube (EGT) collector with compound parabolic collector (CPC) reflector.

Fig.2. Solar collector and PV array

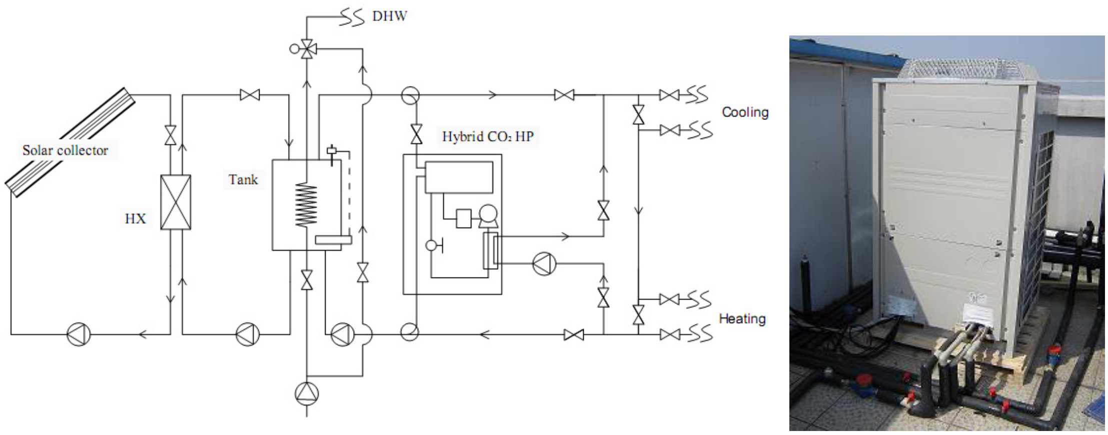


Fig. 3. HVAC&DHW system: (a) Layout of pipe system (Simplified version in cooling mode); (b) Hybrid HP unit [2]

A 8kW air-cooled hybrid CO_2 heat pump (HP) which uses the solar thermal energy to assist an electricity-driven vapor compression (VC) air conditioning is developed. The main components of this device are a small solar thermal-driven Libr absorption chiller and a CO_2 HP. The assisted cooling is mainly used for the further cooling of CO_2, when CO_2 leaves the air-cooled gas cooler. This technology solution can dramatically decrease the outlet temperature of CO_2 which leaves the gas cooler by heat exchange with the chilled water of high temperature (15-18℃) from the absorption chiller. In this case, the proper extra-cooling capacity can be created and a higher COP can be achieved. It also means that electricity consumption of the entire device can be reduced by the solar energy input. In summer, the solar thermal energy, which is harvested by solar water collectors, is transferred from a storage tank (500L) to the loops of HP and DHW. The Hybrid CO_2 HP supplies chilled water to the fan coil unit. In winter, the solar thermal energy can be directly supplied to the radiation floor (70m^2) or radiator. If water temperature of collector tank is not high enough, the CO_2 heat pump is operated as a backup.

One 127W heat recovery ventilator (HRV) is used for recovering both the latent and sensible heat from the exhaust air. In addition, 70 m^2 heating radiant floor was installed for a comparison test with innovation fan coil unit and radiator.

Renewable energy power system installed consists of two photovoltaic (PV) arrays (60m2), a 5kW wind power system, inverters, controllers and meters for export and import. The outputs of polycrystalline and monocrystalline arrays are 2.88kW and 3.84kW, respectively. Figure 4 presents a schematic diagram of the power system.

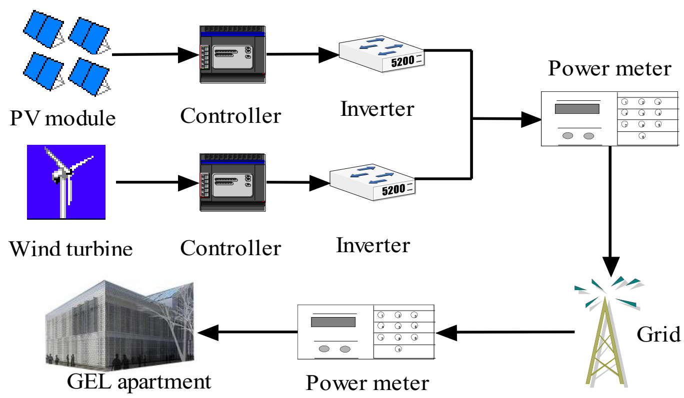


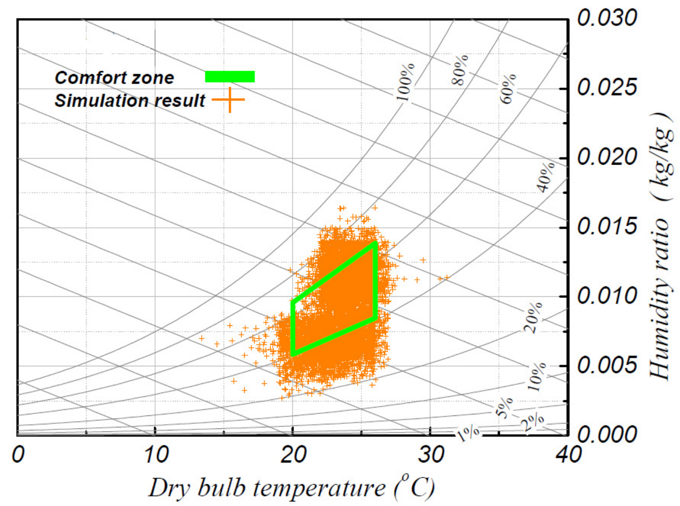
Fig.4. Renewable energy power system

3. Performance Evaluation

The simulation is conducted on TRNSYS platform. The most of models are chosen from the default “type” tree and input parameters are real values from the device manufacturer. The hybrid CO_2 HP is a self-development model based on a set of performance curves from laboratory test. The simulation is conducted under two climate conditions in China: cold and dry, warm and humidity.

3.1. Indoor Comfort

Figure 5 shows psychrometric diagrams of the simulated temperatures and humidity for the indoor environment of NZEB and ambient environment under the climate of warm and humidity as well as a defined comfort zone (20-26°C and 40-65% relative humidity). There are result points for 8760 hours in every figure based on a whole year hourly simulation. A parameter, namely comfortable zone fraction (CZF), which denotes how many result points are inside the comfortable zone, is defined and calculated out. By CZF, the influence from HVAC system on the comfortable level of indoor environment can be evaluated. Similarly, an index, namely, comfortable temperature fraction (CTF), is defined to show how many points are inside the comfortable temperature range (20-26°C). The simulation results show that CZF reaches 45.83% and CTF reaches 92.67%.



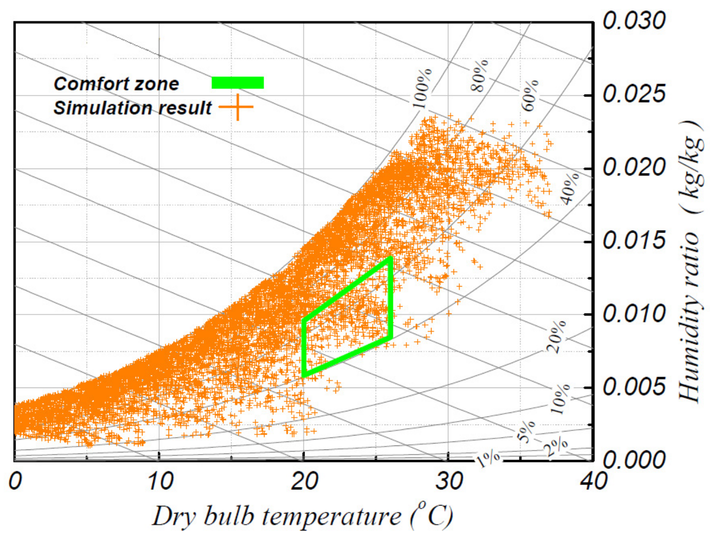


Fig. 5. Temperature and humidity ratio distribution for 8760 hours: (a) Indoor environment; (b) Outdoor environment

3.2. Match Performance

The total electricity consumption for the typical Chinese life style is 84.22 kWh/(m^2a). The HVAC and DHW system, including HP, pumps and terminal units, takes 59.39% of total electricity consumption, as Figure 6 shown. The percentage of electricity consumption in the control system is round 8%. The other parts take approximately one third of the total consumption. In summary, total electricity consumption for the Chinese life style is 7832kWh for one year. Besides, 2.88kW PV, 3.84kW PV and 5kW wind turbine are used as three schemes of renewable energy power supplies, according to the real experiment system. Based on the simulation, 2.88kW polycrystalline PV can output 3767kWh per year. In addition, the electricity generations of 3.84kW PV and 5kW wind turbine are 5072kWh and 4681kWh per year in Shanghai, respectively. Thus, three cases regarding the renewable energy supply are proposed to offset the energy consumption of maintenance (or called operation), as shown in Figure 6. The energy solution of the first case is a combination of two PV arrays (6.72kW). The total electricity generation is 8839kWh per year. The annual electricity consumption can be offset by the generation of this solution and surplus 1007kWh electricity generation can be available to shorten the recovery time of investment.

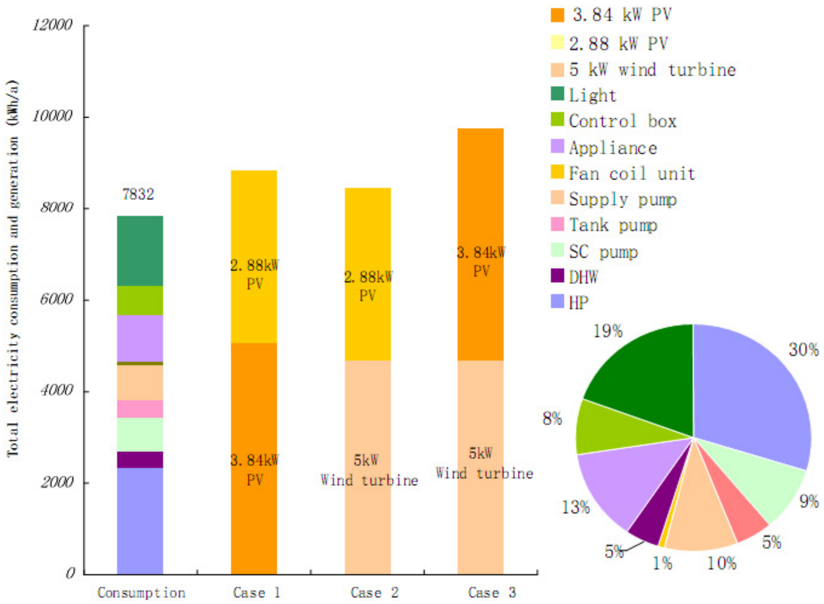


Fig. 6. Steady match performance: balance between consumption and generation, distribution of energy consumption

4. Summary

Solar energy is an important consideration for renewable energy input in this case. The integration solution is the solar thermal driven cooling and heating system, including solar air-conditioning, domestic hot water system, and combined heating supply system. Because of the intermittent supply and high cost, the independent solar HVAC and DHW system still keeps at a demonstration stage, even though all the products are available in the market. Another solution is the PV array that is widely used in the existed NZEB projects. Due to limited surface area of the building body and the pollution of production process, existed silicon-based PV technology limits further development of NZEB and meets a challenge of technology update.

With respect to the match performance of NZEB, although solar energy can be used as thermal and power source, its unsteady increases the mismatching percentage between source and demand, thus a delicate design is necessary. Dynamic match performance will be analyzed in terms of on-site energy fraction (OEF) and on-site energy matching (OEM) in the future study.

Acknowledgements

The case study under the Tianjin weather conditions is financially supported by National High-Technology Research and Development Program ("863" program) of China under Grant number 2015AA050403.

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Biography

Shuai Deng (corresponding author), Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, MOE, School of Mechanical Engineering, Tianjin University. He devotes himself to the study of renewable energy system, distributed energy system, net zero energy building, carbon capture and storage and so on.